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Suppression of invasive topmouth gudgeon Pseudorasbora parva *by native pike* Esox lucius *in ponds*

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ABSTRACT

1. Asian topmouth gudgeon *Pseudorasbora parva* has been recognized as a highly invasive cyprinid fish species in Europe that may present risk to native fish communities.
2. The present study aimed to investigate whether a native piscivorous fish, pike *Esox lucius*, is able to reduce the establishment success and invasiveness of topmouth gudgeon in shallow ponds. A large-scale, replicated whole-pond experiment was performed in which ponds were spontaneously colonized by topmouth gudgeon and exposed to experimental native fish communities with and without pike.
3. The results of the present study provide evidence for strong negative effects of pike stocking on the abundance and biomass of topmouth gudgeon, while no effects on native fish species were found. The present study suggests that the presence of native pike can considerably enhance the biotic resistance of fish communities against invasion by topmouth gudgeon.
4. It is argued that the resistance of fish communities against invasion by exotic species may in some cases be enhanced by management strategies that reinforce the presence and abundance of pike.

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KEY WORDS: pond; biological control; ecosystem approach; invasive topmouth gudgeon; indigenous pike

INTRODUCTION

Invasions by non-indigenous biota are recognized as a major human-induced environmental threat that adversely affects native biodiversity and the functioning and services of a variety of ecosystems worldwide (Mack *et al.*, 2000; Sala *et al.*, 2000; Hulme, 2007; Vilà *et al.*, 2009; Ehrenfeld, 2010; Vilà *et al.*, 2011). In Europe, topmouth gudgeon *Pseudorasbora parva* has been recognized as a highly invasive cyprinid fish species since its first unintended introduction from east Asia in 1960 via fish translocations (Gozlan *et al.*, 2002; Pinder *et al.*, 2005). This continuing invasion probably

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results from natural dispersal through river networks and unintended stocking, and is thought to be facilitated by its opportunistic, flexible life-history characteristics (e.g. early sexual maturity, high reproductive rate, batch spawning and parental nest guarding), as well as by its ability to survive in degraded environmental conditions (Ricciardi and Rasmussen, 1998; Rosecchi *et al*., 2001; Gozlan *et al*., 2010a, b). Topmouth gudgeon might present a risk to native communities by rapidly developing high population densities, which may exert interspecific exploitative competition (Declerck *et al*., 2002; Britton *et al*., 2007), alter trophic interactions (Britton *et al*., 2010) and change ecosystem functioning. Additional concern arises from disease transmission and facultative parasitism (Gozlan *et al*., 2005, 2010a).

Current research in invasion biology is primarily focused on the threats and the underlying mechanism of species invasions, rather than providing sustainable and practical solutions for management (Hulme, 2003, 2006). In addition to preventative measures, such as trade legislation, effective approaches for eradication or suppression of local populations are frequently needed to impede further establishment and wider dispersal of alien species (Simberloff, 2009). So far, only a limited number of eradication programmes for topmouth gudgeon have been reported (Britton *et al*., 2008) and they mainly involve piscicide application, such as rotenone. Despite its success in local, isolated populations, the application of rotenone has major disadvantages, because it is not species-specific (Ling, 2003), and because its application is labour-intensive and costly (Britton *et al*., 2008). Furthermore, rotenone has only short-term effects (Ling, 2003), and therefore provides no sustainable, long-term protection against new invasions.

The objective of this study was to investigate whether a native piscivorous fish, pike *Esox lucius*, is able to reduce the establishment success and invasiveness of Asian topmouth gudgeon in shallow ponds. A large-scale pond experiment (n=12) was performed in which ponds that were spontaneously colonized by topmouth gudgeon were exposed to experimental fish treatments with and without pike.

METHODS

Study area

The experiment was performed in the Vijvergebied Midden-Limburg, situated in the north-eastern part of Belgium (50° 59’ 00.92" N; 5° 19’ 55.85" O and surroundings), and part of the De Wijers area (Lemmens *et al*., 2013). The region comprises more than 1000 shallow artificial ponds (average depth: 81 cm, average size: 0.9 ha) (Hermy, 1993), many of which were used historically for extensive fish farming. Most ponds are indirectly connected with the River Demer basin via two small streamlets (Oude and Nieuwe Roosterbeek) and are interconnected by a complex network of rivulets. Fish farming is still an important local practice, but most ponds nowadays are protected by national and international legislation (Birds Directive (79/409/EEC) and Habitats Directive (92/43/ECC)) and are managed for purposes of nature conservation. Topmouth gudgeon was first reported in Belgium in 1992 and is now widespread in the country (Verreycken *et al*., 2007), including the pond region Vijvergebied Midden-Limburg.

Experimental design

As part of a larger experiment 12 ponds (0.239–1.993 ha) were drained during autumn 2008 (Supporting Information, Figure S1). This resulted in the removal of the resident fish communities. The ponds were refilled in early spring 2009 (February). During refilling, fine-mesh stainless steel grids (mesh width, 2 mm) were placed at the inlets to minimize the entrance of wild fish. After filling, all connections with rivulets or other ponds were closed. The ponds were subsequently stocked with a total fish biomass of 100 kg ha^{-1} (late March 2009). To evaluate the effect of pike, six randomly selected ponds were stocked with a combination of pike (6 weeks old juveniles, 150 individuals ha^{-1}, stocked in early May), planktivores (rudd *Rutilus rutilus*, roach *Scardinius erythrophthalmus*, ide *Leuciscus idus* and small perch *Perca fluviatilis*, 50 kg ha^{-1}) and common carp *Cyprinus carpio* (1 yr old common carp (K1); 50 kg ha^{-1}) (further referred to as ‘pike ponds’). The other six ponds were stocked with the same fish combinations, but received no pike (further referred to as 'no pike' ponds) (Figure S1). More details on the stocked fish communities can be found in Table 1. Pike fingerlings were provided by the fish hatchery of the Research Institute for Nature and Forests (INBO) and were of autochthonous origin, whereas other species were obtained from a local fish farm. Topmouth gudgeon was not stocked. Previous experiences in the study area show that topmouth gudgeon populations can quickly re-establish populations in ponds, even after a long period of drought and when ponds are filled using the above-mentioned grids, presumably because meshes of the grids are too large to retain topmouth gudgeon juveniles. In some cases, local topmouth gudgeon populations may also have survived the winter in small puddles and pools together with other fish species. This was probably the case in only a minority of ponds, given that most ponds seemed entirely dry throughout the winter. The experiment lasted almost 1.5 yr (from spring 2009 to autumn 2010).

Data collection

Total biomass, species composition and size distribution of the fish community in each pond were assessed at the end of the experiment (autumn 2010). Fish communities were harvested by professional local fish farmers by draining the ponds and by using seine nets. The collected fish were sorted into different size fractions. Large size classes of common carp, ide, rudd and roach were sorted manually. The remaining fish were sorted by using multiple consecutive nets with decreasing mesh widths (5 cm, 2 cm, 1 cm, 0.5 cm) suspended in the water. For 30 min fish were allowed to swim through the nets and sort themselves according to body size. The total weight of each size fraction of each pond was determined and one subsample (at least 10 individuals for common carp, ide and large rudd and roach; > 30 individuals for subsamples from smaller size classes (ranging between 1 and 16 cm)) were taken from each of these fractions to determine the species identity, standard body length and body weight of individuals.

Table 1. Standard length and total biomass of the stocked species and individuals

	median standard length (min-max)	stocked biomass ($kg\,ha^{-1}$)
Perch (*Perca fluviatilis*)	9.5 cm (8.5 - 13.5)	3
Roach (*Rutilus rutilus*)	16.3 cm (7.0 - 23.0)	21
Rudd (*Scardinius erythrophthalmus*)	12.0 cm (9.0 - 21.0)	21
Ide (*Leuciscus idus*)	8.5 cm (7.5 - 9.5)	5
Common carp (*Cyprinus carpio*)	11.5 cm (9.5 - 14)	50
Pike (*Esox lucius*)*	9 cm (7–13)	0.63
Total fish biomass		100

*150 fingerlings per hectare (average individual body weight 4.2 g).

In addition, data on important pond characteristics were collected to check whether differences among fish communities in the different treatments were coincidently caused by systematic differences among ponds. Pond surfaces were calculated once in 2009 with the GIS software package ArcView GIS 3.2a (ESRI, Inc.). The percentage of pond area covered by submerged, emergent and floating vegetation was visually estimated in August of both years (2009 and 2010). Water transparency and chlorophyll a concentrations were determined each month from March until October in both years using a Snell tube (Louette and De Meester, 2005) and a handheld fluorometer (AquaFluor, Turner Designs, Sunnyvale, CA), respectively.

Data analysis

The species and size composition of the fish communities were reconstructed by combining the compositional data from the subsamples with the biomass data of the corresponding size fractions. For each species, age classes were assigned to length cohorts. Data for rudd and roach were pooled together as planktivorous cyprinids (further referred to as YOY cyprinids, Y1Y cyprinids and adult cyprinids).

Non-parametric Mann–Whitney U-tests were used to test for differences in biomass and abundance of topmouth gudgeon, common carp, ide, YOY cyprinids, Y1Y cyprinids, adult cyprinids and the total fish community between both treatments ('pike' and 'no pike'). Redundancy analysis (RDA) was applied on logarithmically transformed and standardized environmental data to test formally for differences in pond characteristics among treatments for each of the two years.

Mann–Whitney U-tests were performed in STATISTICA v10 (StatSoft, Inc., Tulsa, Oklahoma) and RDA-analyses were done with the software package CANOCO v4.5 (ter Braak and Šmilauer, 2002).

RESULTS

No evidence was found for systematic differences among 'pike' and 'no pike' ponds for local environmental pond variables, such as surface area, cover by macrophyte functional groups, phytoplankton biomass and water transparency (RDA: $R^2 = 4.3\%$, $F = 0.445$, $P = 0.859$ and $R^2 = 3.7\%$, $F = 0.388$, $P = 0.814$ for 2009 and 2010 respectively) (Figure 1).

At the end of the experiment, pike was exclusively found to be present in ponds of the 'pike' treatment. The mean abundance and biomass of adult pike in these ponds was 40 ind ha^{-1} (min = 10 ind ha^{-1}, max = 70 ind ha^{-1}) and 13.67 kg ha^{-1} (min = 5.7 3 kg ha^{-1}, max = 22.16 kg ha^{-1}) respectively. Average body size and weight of adult pike was 32.9 cm (min = 18.2 cm, max = 54.3 cm) and 0.992 kg (min = 0.06 kg, max = 1.662 kg) respectively. YOY pike were found in only one pond (126 ind ha^{-1}, 3.96 kg ha^{-1}).

Total fish biomass had increased in all ponds from an initial 100 kg ha^{-1} to an average of approximately 290 kg ha^{-1} at the end of the experiment (Figure S2). The presence of pike had no effect on total fish community biomass. However, pike stocking had a strong negative effect on the abundance and biomass of topmouth gudgeon in the ponds (Mann–Whitney U-test, $P < 0.026$) (Figure 2). Topmouth gudgeon occurred in all six ponds of the 'no pike' treatment, with abundances and biomasses ranging from 12 to 50 224 ind ha^{-1} and 0.03 to 115 kg ha^{-1}, respectively. Conversely, topmouth gudgeon was found only in two of the six ponds with pike. The total abundance and biomass of topmouth gudgeon in these two ponds was 372 ind ha^{-1} (0.44 kg ha^{-1}) and 226 ind ha^{-1} (1 kg ha^{-1}). The body size distribution of topmouth gudgeon populations did not systematically differ between 'pike' and 'no pike' ponds (Figure S3).

Adult planktivorous cyprinids (rudd and roach) had reproduced in both treatments in both years (2009 and 2010) and their populations therefore comprised YOY and Y1Y fish. The number of ponds with juvenile cyprinids was higher in the 'pike' treatments compared with the 'no pike' treatment (2009: six versus three, 2010: six versus four). Common carp and ide did not reproduce and all individuals of these populations belonged to one single year class. In addition to topmouth gudgeon, most ponds contained a small fraction of fish species that had not been stocked as part of the experiment (mainly gibel carp *Carassius gibelio* and to a lesser extent pumpkinseed sunfish *Lepomis gibbosus*). The density of any of the individual species or year classes did not significantly differ between the experimental treatments (Figure 3).

DISCUSSION

The development of effective management programmes for invasive species is a current challenge for invasion biology (Hulme, 2006). Despite some important initiatives, the geographical expansion of topmouth gudgeon is still continuing (Gozlan *et al.*, 2010a) and there is an urgent need for cost-efficient strategies that can help to contain, suppress or eradicate populations (Copp *et al.*, 2005). Approaches that do not focus solely on the invasive target species, but also consider the characteristics of the native communities may have the greatest potential to be successful, especially in the longer term (Hulme, 2006).

In the present whole-pond experiment, strong negative effects of pike stocking on the abundance and biomass of Asian topmouth gudgeon were found. These results indicate that native pike has substantial potential to prevent the establishment or proliferation of populations of topmouth gudgeon in shallow ponds, at least on time scales similar to that of the present experiment. Indeed, after a dry period before the start of the experiment, topmouth gudgeon re-established very quickly in all ponds without pike but occurred in only two of the six ponds with pike. The average biomass of these two populations also remained on average 34-fold lower than the average of the ponds without pike.

The results of this study provide strong experimental evidence that the presence of pike can considerably enhance the biotic resistance of fish communities against invasion by topmouth gudgeon. Predator-driven resistance against alien species invasions has been shown both for terrestrial and aquatic ecosystems (Baltz and Moyle, 1993; Byers, 2002; deRivera *et al.*, 2005; Gruner, 2005; Marsh-Matthews *et al.*, 2013), but

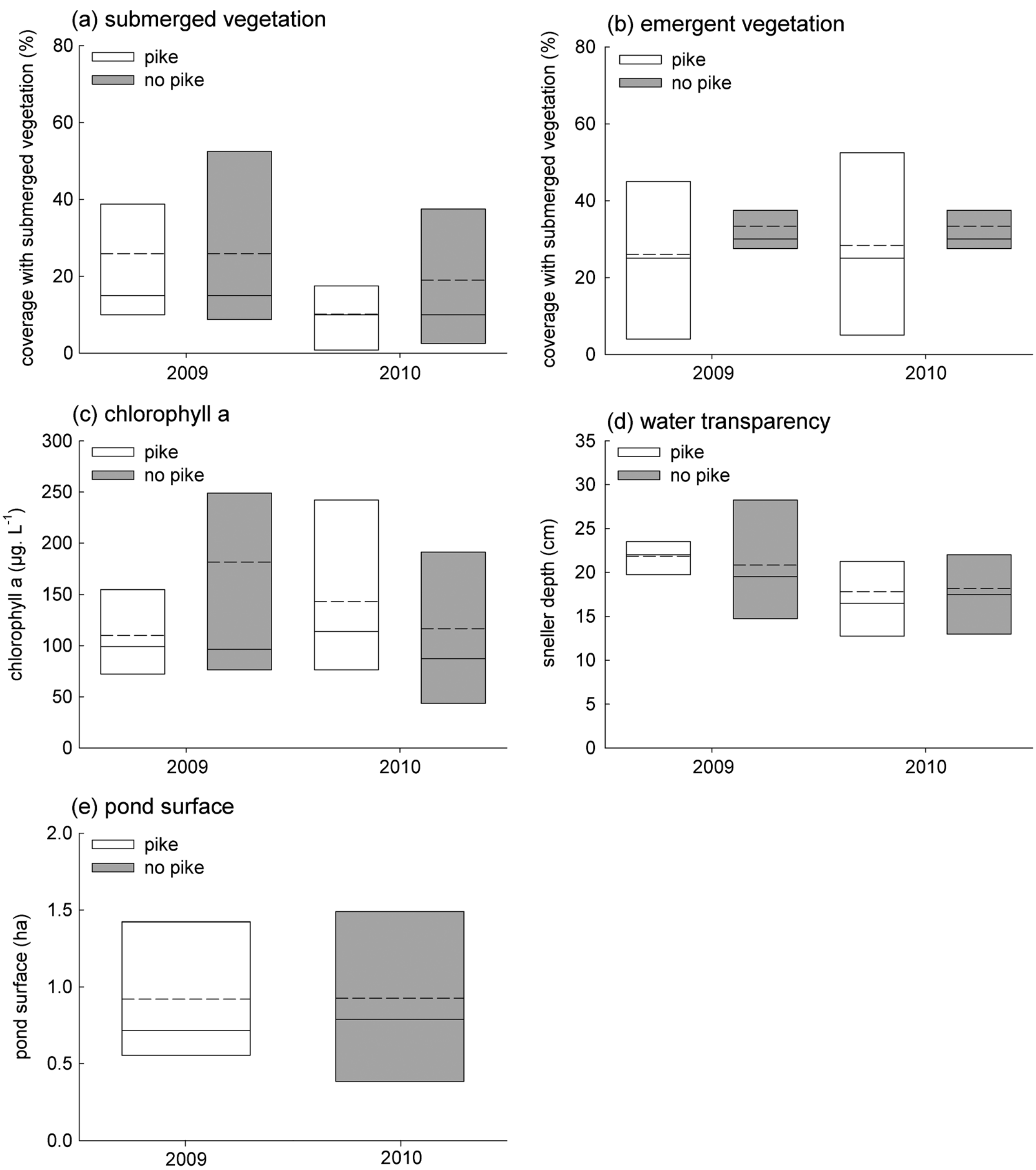

Figure 1. Box plots with the median (solid line) and the average (dotted line) of different pond characteristics of 'pike' and 'no pike' ponds in 2009 and 2010. (a) Percentage cover of submerged vegetation; (b) percentage cover of emergent vegetation; (c) chlorophyll a concentration; (d) water transparency; and (e) pond surface. Boxes represent the 25th and 75th percentile.

has, to our knowledge, only sparsely been implemented in management programmes. It is surprising that no evidence was found for the effects of pike stocking on the abundance and biomass of native fish species or the age structure of their populations. This suggests that the predation pressure of pike was stronger on topmouth gudgeon than on other native fish species, possibly as a result of (a) preferential feeding of pike on topmouth gudgeon, (b) a higher predation efficiency of pike on topmouth gudgeon, and (c) a mismatch in the timing of pike stocking (early May) and the reproduction of native species. To date, there is no information on how selective pike is in its predation on topmouth gudgeon, and to what extent this predator displays a preference to feed on topmouth gudgeon compared with other fish species. Given the lack of a common natural history with pike, topmouth gudgeon may also be more

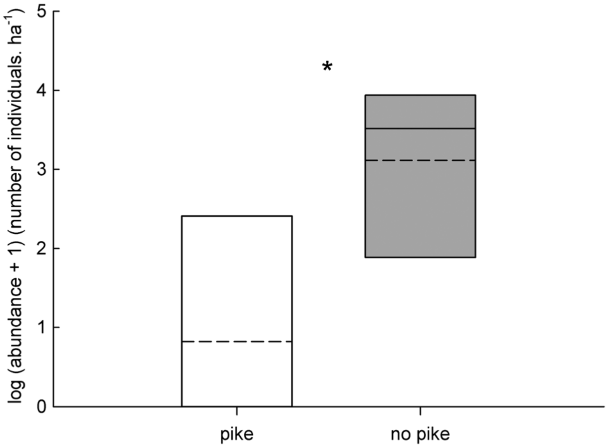

Figure 2. Box plot with the median (solid line) and the average (dashed line) abundance (individuals ha^{-1}) of topmouth gudgeon in 'pike' and 'no pike' ponds at the end of the experiment (shown in white and grey respectively). Boxes represent the 25th and 75th percentile. (* Mann–Whitney U-test, significance level $P < 0.05$).

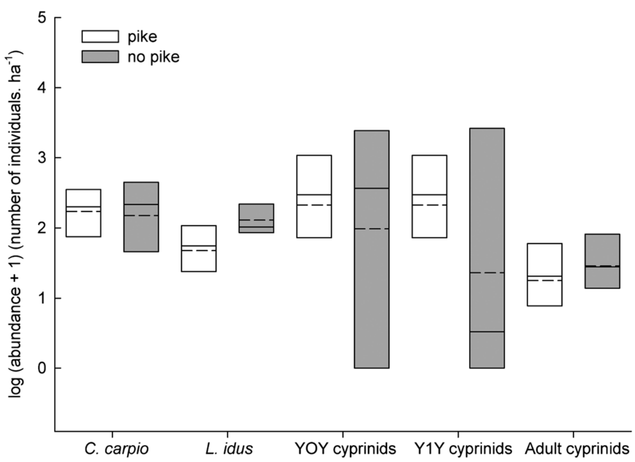

Figure 3. Box plot with the median (solid line) and the average (dashed line) abundance (individuals ha^{-1}) of *Cyprinus carpio*, *Leuciscus idus*, YOY cyprinids, Y1Y cyprinids and adult cyprinids in ponds with and without pike stocking at the end of the experiment (shown in white and grey respectively). Boxes represent the 25th and 75th percentile.

vulnerable to pike predation than other, indigenous fish species because it has not had the time yet to evolve effective predator avoidance behaviour or escape responses. A mismatch in the timing of pike stocking and the reproduction of the introduced cyprinid prey populations (Skov and Nilsson, 2007) may have reduced pike predation pressure during the first year of the experiment, although we doubt that it can entirely account for the lack of any pike effect, given that suitable size classes of the indigenous prey species were available to pike during the second year of the experiment. It is therefore also possible that differential predation may have indirectly enhanced the performance of indigenous fish species through a release of interspecific competition leading to compensatory growth and reproduction. Indeed, small cyprinid species like rudd and roach tended to reproduce successfully more often in the ponds with than in the ponds without pike stocking, although analyses of fish body condition indices and population size structure revealed no differences between the treatments (data not shown).

Differential colonization rates of topmouth gudgeon as the result of behavioural avoidance of ponds with pike can be excluded as a potential explanation for the observed differences in population abundances between the experimental treatments because pike was stocked only after all connections with adjacent ponds and rivulets had been closed. Furthermore, the lack of systematic differences in pond characteristics among 'pike' and 'no pike' ponds suggests that environmental variability has not been the driver behind the observed patterns.

It is known that the expansion of many invasive species can be strongly facilitated by human-induced habitat degradation and disturbances (Gurevitch and Padilla, 2004). In Europe as well as in other parts of the world, fish stocks have been altered intensely by humans for aquaculture or for recreational fisheries. In many cases, this has resulted in a general decline of indigenous piscivorous fish. Based on the results of the present study, we argue that the resistance of fish communities against invasion by exotic species may in some cases be enhanced by management strategies that reinforce the presence and abundance of indigenous pike in habitats in which they naturally occur. Such strategies can comprise measures that improve the habitat quality for pike, as well as scientifically based restocking programmes in which the genetic origin of the fish and the effective need for restocking are taken into account.

In conclusion, the results of the present experiment provide evidence that management directed at the enhancement of pike populations can strongly contribute to the effective suppression of invasive topmouth gudgeon, at least at the scale of small shallow lakes and ponds. Extrapolation of the results to larger lakes should, however, be done with care. Small pike, as used in the present experiment, are strongly associated with vegetation. In larger lakes with extensive pelagic habitat, topmouth gudgeon may be well able to reduce predation from pike, especially when larger pike are absent or scarce. In comparison with eradication programmes with rotenone, the reintroduction of pike fingerlings is feasible, cost-effective, uncontroversial, and sustainable. There is also extensive understanding of how to enhance and manage pike populations, given the longstanding tradition of pike stocking in the restoration of shallow ponds and lakes (Skov and Nilsson, 2007; Jeppesen *et al.*, 2012). Although stocking with pike has been a widely applied measure in biomanipulation programmes, its effectiveness is increasingly being questioned (Skov and Nilsson, 2007). Nevertheless, we believe that stocking juvenile pike can still be a valuable measure in specific cases where the aim is to restore the ecological integrity of fish communities or, as shown in this study, where the suppression of invasive topmouth gudgeon is the objective.

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